**CHE1031 HW set 4: Stoichiometry of chemical reactions - KEY**

*Please solve these problems on green engineering graph paper.*

*Problems are assigned at each class meeting and are due at the next class.*

*Please number each problem, show all work for credit and box your answer.
Note that answers to quantitative problems are provided in blue.*

**4.1: Writing and balancing chemical equations**

**1.** What does it mean to say an equation is balanced? Why is it important for an equation to be balanced?
Balanced equations have the same types and numbers of atoms on both sides, the reactants side and the products side. Balanced equations obey the law of conservation of mass!

**2.** Consider ‘molecular’, complete ionic, and net ionic chemical equations.

(a) What is the difference between these types of equations?

(b) In what circumstance would the complete and net ionic equations for a reaction be identical?

(a) Molecular equations (aka plain old balanced chemical equations) show molecules with net charges of zero. Complete ionic equations dissociate all aqueous solutions into ions. Net ionic equations show the change that occurs in chemical reactions and do not show spectator ions that are the same in reactants and products.

(b) If no spectator ions were present then complete and net ionic equations would be identical.

**3.** Balance these chemical equations.

(a) PCl5(*s*) + H2O(*l*) ⟶ POCl3(*l*) + HCl(*aq*)

(b) H2(*g*) + I2(*s*) ⟶ HI(*s*)

(c) Fe(*s*) + O2(*g*) ⟶ Fe2O3(*s*)

(d) Na(*s*) + H2O(*l*) ⟶ Na(OH)(*aq*) + H2(*g*)

(e) (NH4)2(Cr2O7)(*s*) ⟶ Cr2O3(*s*) + N2(*g*) + H2O(*g*)

(f) P4(*s*) + Cl2(*g*) ⟶ PCl3(*l*)

(g) PtCl4(*s*) ⟶ Pt(*s*) + Cl2(*g*)

(a) PCl5(s) + H2O(l) ⟶ POCl3(l) + **2**HCl(aq)

(b) H2(g) + I2(s) ⟶ **2**HI(s)

(c) **4**Fe(s) + **3**O2(g) ⟶ **2**Fe2O3(s)

(d) **2**Na(s) + **2**H2O(l) ⟶ **2**Na(OH)(aq) + H2(g)

(e) (NH4)2(Cr2O7)(s) ⟶ Cr2O3(s) + N2(g) + **4**H2O(g)

(f) P4(s) + **6**Cl2(g) ⟶ **4**PCl3(l)

(g) PtCl4(s) ⟶ Pt(s) + **2**Cl2(g)

**4.** Write a balanced chemical equation describing each of the following chemical reactions.

(a) Solid calcium carbonate is heated and decomposes to solid calcium oxide and carbon dioxide gas.

(b) Gaseous butane, C4H10, reacts with diatomic oxygen gas to yield gaseous carbon dioxide and water vapor.

(c) Aqueous solutions of magnesium chloride and sodium hydroxide react to produce solid magnesium hydroxide and aqueous sodium chloride.

(d) Water vapor reacts with sodium metal to produce solid sodium hydroxide and hydrogen gas.

(a) Ca(CO3)(s) + heat 🡪 CaO(s) + CO2(g)

(b) C4H10(g) + 13/2O2(g) 🡪 4CO2(g) + 5H2O(g) [Multiply all coefficients by 2 if you like.]

(c) MgCl2(aq) + 2Na(OH)(aq) 🡪 Mg(OH)2(s) + 2NaCl(aq)

(d) 2H2O(g) + 2Na(s) 🡪 2Na(OH)(s) + H2(g)

**5.** From each of these balanced chemical equations, write:

(i) the complete ionic; and

(ii) the net ionic equations.

(a) K2(C2O4)(aq) + Ba(OH)2(aq) ⟶ 2K(OH)(aq) + Ba(C2O4)(s)

(b) Pb(NO3)2(aq) + H2(SO4)(aq) ⟶ Pb(SO4)(s) + 2H(NO3)(aq)

(c) Ca(CO3)(s) + H2(SO4)(aq) ⟶ Ca(SO4)(s) + CO2(g) + H2O(l)

(a) ~~2K~~~~+1~~ + (C2O4)-2 + Ba+2 + ~~2(OH)~~~~-~~1 ⟶ ~~2K~~~~+1~~ ~~+ 2(OH)~~~~-1~~ + Ba(C2O4)(s)

(b) Pb+2 + ~~2(NO3)~~~~-1~~ ~~+ 2H~~~~+1~~ + (SO4)-2 ⟶ Pb(SO4)(s) + ~~2H~~~~+1~~ ~~+ 2(NO3)~~~~-1~~

(c) Ca(CO3)(s) + 2H+1 + (SO4)-2 ⟶ Ca(SO4)(s) + CO2(g) + H2O(l)

**4.2: Classifying chemical reactions**

**6.** Indicate what type, or types, of reaction each of these balanced equations represents.

(a) H2O(g) + C(s) ⟶ CO(g) + H2(g)

(b) 2K(ClO3)(s) ⟶ 2KCl(s) + 3O2(g)

(c) Al(OH)3(aq) + 3HCl(aq) ⟶ AlCl3(aq) + 3H2O(l)

(d) Pb(NO3)2(aq) + H2(SO4)(aq) ⟶ Pb(SO4)(s) + 2H(NO3)(aq)

(a) exchange, displacement, redox

(b) decomposition

(c) exchange & acid-base

(d) exchange & precipitation

**7.** Determine the oxidation numbers of the elements in the compounds listed.
(None of the oxygen-containing compounds are peroxides or superoxides.)

(a) H3(PO4)

(b) Al(OH)3

(c) SeO2

(a) H +1, P +5, O -2

(b) Al +3, O -2, H +1

(c) Se +4, O -2

**8.** Classify the following as acid-base reactions or oxidation-reduction reactions.
 *Try assigning oxidation numbers.*

(a) Na2S(aq) + 2HCl(aq) ⟶ 2NaCl(aq) + H2S(g)

(b) 2Na(s) + 2HCl(aq) ⟶ 2NaCl(aq) + H2(g)

(c) Mg(s) + Cl2(g) ⟶ MgCl2(s)

(a) Na2S(aq) + 2HCl(aq) ⟶ 2NaCl(aq) + H2S(g)
 +1/-2 +1/-1 +1/-1 +1/-2 so acid-base

(b) 2Na(s) + 2HCl(aq) ⟶ 2NaCl(aq) + H2(g)
 0 +1/-1 +1/-1 0 so redox

(c) Mg(s) + Cl2(g) ⟶ MgCl2(s)
 0 0 +2/-1 so redox

**9.** Complete and balance these acid-base equations.

(a) A solution of H(ClO4) is added to a solution of Li(OH).

(b) Aqueous H2SO4 reacts with Na(OH).

(c) Ba(OH)2 reacts with HF gas.

(a) H(ClO4)(aq) + Li(OH)(aq) 🡪 H2O(l) + Li(ClO4)(aq)

(b) H2(SO4)(aq) + 2Na(OH)(aq) 🡪 2H2O(l) + Na2(SO4)

(c) Ba(OH)2 reacts with HF gas.
 Ba(OH)2(aq) + 2HF(g) 🡪 2H2O(l) + BaF2(s)

**10.** Write the complete, total ionic, and net ionic equations for the following reactions:

(a) Ca(OH)2(aq) + H(C2H3O2)(aq) ⟶

(b) H3(PO4)(aq) + CaCl2(aq) ⟶

(a) Ca(OH)2(aq) + 2H(C2H3O2)(aq) ⟶ Ca(C2H3O2)2(aq) + 2H2O(l)
 ~~Ca~~~~+2~~ + 2(OH)-1 + 2H+1 + ~~2(C2H3O2)~~~~-1~~⟶ ~~Ca~~~~+2~~ ~~+ 2(C2H3O2)~~~~-1~~ + 2H2O(l)

(b) 2H3(PO4)(aq) + 3CaCl2(aq) ⟶ Ca3(PO4)2(s) + 6HCl(aq)
 ~~6H~~~~+1~~ + 2(PO4)-3 + 3Ca+2 + ~~6Cl~~~~-1~~ ⟶ Ca3(PO4)2(s) + ~~6H~~~~+1~~ ~~+ 6Cl~~~~-1~~

**11.** Write balanced chemical equations for the reactions used to prepare each of the following compounds from the given starting material(s). In some cases, additional reactants may be required.

(a) solid ammonium nitrate from gaseous molecular nitrogen via a two-step process (first reduce the nitrogen to ammonia, then neutralize the ammonia with an appropriate acid)

(b) gaseous hydrogen bromide from liquid molecular bromine via a one-step redox reaction

(c) gaseous H2S from solid Zn and S via a two-step process (first a redox reaction between the starting materials, then reaction of the product with a strong acid)

(a) (1) N2(g) + 3H2(g) 🡪 2NH3(g); (2) NH3(g) + H(NO3)(aq) 🡪 (NH4)(NO3)

(b) Br2(l) + H2(g) 🡪 2HBr(g)

(c) (1) 8Zn(s) + S8(s) 🡪 8ZnS(s); (2) ZnS(s) + 2HCl(aq) 🡪 H2S(g) + ZnCl2(aq)

**12.** Complete and balance each of the following half-reactions (steps 2–5 in half-reaction method):

(a) Sn+4(aq) ⟶ Sn+2(aq)

(b) Ag(NH3)+2(aq) ⟶ Ag(s) + NH3(aq)

(c) Hg2Cl2(s) ⟶ Hg(l) + Cl−1(aq)

(d) H2O(l) ⟶ O2(g) (in acidic solution)

(e) IO3−1(aq) ⟶ I2(s)

(f) SO3-2(aq) ⟶ SO4-2(aq) (in acidic solution)

(g) MnO4-1(aq) ⟶ Mn+2(aq) (in acidic solution)

 (a) Sn+4(aq) + **2e-** ⟶ Sn+2(aq)

(b) Ag(NH3)+2(aq) + **2e-** ⟶ Ag(s) + NH3(aq)

(c) Hg2Cl2(s) + **2e-**⟶ **2**Hg(l) + **2**Cl−1(aq)

(d) **2**H2O(l) ⟶ O2(g) (in acidic solution) + **4H+1 + 4e-**

(e) **2**IO3−1(aq) **+ 12H+1 + 10e-** ⟶ I2(s) + **6H2O**

(f) SO3-2(aq) + **H2O** ⟶ SO4-2(aq) (in acidic solution) + **2H+1 + 2e-**

(g) MnO4-1(aq) + **8H+1 + 5e-** ⟶ Mn+2(aq) (in acidic solution) + **4H2O**

**13.** Balance the following equation according to the half-reaction method:

Br2(*l*) + SO2(*g*) ⟶ Br−1(*aq*) + SO4-2(*aq*) (in acid)

Br2(*l*) + **2e-** ⟶ **2**Br−1(*aq*) (in acid)
 SO2(*g*) + **2H2O** ⟶ SO4-2(*aq*) (in acid) + **4H+1 + 2e-**

**4.3: Reaction stoichiometry**

**14.** Write the balanced equation, then determine the information requested in each of the following:

(a) The number of moles and the mass of chlorine, Cl2, required to react with 10.0 g of sodium metal, Na, to produce sodium chloride, NaCl.

(b) The number of moles and the mass of oxygen formed by the decomposition of 1.252 g of mercury (II) oxide.

(c) The number of moles and the mass of sodium nitrate, Na(NO3), required to produce 128 g of oxygen. (Na(NO2) is the other product.)

Strategy for all: g 🡪 mol 🡪 mol 🡪 g

 MW stoich MW

(a) 2Na(s) + Cl2(g) 🡪 2NaCl(s)
 10.0 g Na 1 mol 1 mol Cl2 70.9 g = 15.4 g Cl2

 22.99 g 2 mol Na 1 mol Cl2

 🡪 0.217 mol Cl2

(b) 2HgO 🡪 2Hg + O2

 1.252 g 1 mol HgO 1 mol O2 = 2.890 E-3 mol O2 31.98 g = 0.09243 g

 216.58 g 2 mol HgO 1 mol O2

(c ) 2Na(NO3) 🡪 O2 + 2Na(NO2)

 128 g O2 1 mol O2 2 mol Na(NO3) = 8.01 mol Na(NO3) 84.97 g = 680.6 g

 31.98 g 1 mol O2 1 mol Na(NO3)

**15.** H2 is produced by the reaction of 118.5 mL of a 0.8775-M solution of H3(PO4) according to the following equation: 2Cr + 2H3(PO4) ⟶ 3H2 + 2Cr(PO4).

Determine the number of moles and mass of H2.

 2Cr + 2H3(PO4) ⟶ 3H2 + 2Cr(PO4)

 118.5 mL

 0.8775 M 🡪 mol 🡪 mol H2 🡪 H2 (g)

 0.1185 L 0.8775 mol H3(PO4) 3 mol H2 = 0.1560 mol 2.02 g = 0.3151 g

 1 L 2 mol H3(PO4) 1 mol

**16.** I2 is produced by the reaction of 0.4235 mol of CuCl2 according to the following equation:

2CuCl2 + 4KI ⟶ 2CuI + 4KCl + I2.

(a) How many molecules of I2 are produced?

(b) What mass of I2 is produced?

2CuCl2 + 4KI ⟶ 2CuI + 4KCl + I2

0.4235 mol 🡪 mol I2 🡪 g I2

(a) 0.4235 mol 1 mol I2 6.02 E23 molecules I2 = 1.275 E23 molecules I2

 2 mol CuCl2 1 mol

(b) 0.4235 mol 1 mol I2 253.80 g = 53.74 g I2

 2 mol CuCl 1 mol

**17.** Urea, CO(NH2)2, is manufactured on a large scale for use in producing urea-formaldehyde plastics and as a fertilizer. What is the maximum mass of urea that can be manufactured from the CO2 produced by combustion of 1.00 E3 kg of carbon followed by the reaction?

CO2(g) + 2NH3(g) ⟶ CO(NH2)2(s) + H2O(l)

C + O2 🡪 CO2

1 E3 kg 🡪 g 🡪 mol 🡪 mol CO2 then apply mol CO2 to the equation in the problem

1 E6 g C 1 mol C 1 mol CO2 = 8.33 E4 mol CO2

 12.01 g 1 mol C

8.33 E4 mol CO2 1 mol CO(NH2)2 60.06 g = 5.00 E6 g CO(NH2)2

 1 mol CO2 1 mol CO(NH2)2

**18.** What volume of 0.750 M hydrochloric acid solution can be prepared from the HCl produced by the reaction of 25.0 g of NaCl with excess sulfuric acid?

NaCl(s) + H2(SO4)(l) ⟶ HCl(g) + Na(HSO4)(s)

25.0 g excess 0.750 M

 L ?
 g 🡪 mol 🡪 mol 🡪 L

25.0 g 1 mol 1 mol HCl 1 L = 0.570 L of HCl

 58.44 g 1 mol NaCl 0.750 mol

**19.** What volume of a 0.2089 M KI solution contains enough KI to react exactly with the Cu(NO3)2 in 43.88 mL of a 0.3842 M solution of Cu(NO3)2?

2Cu(NO3)2 + 4KI ⟶ 2CuI + I2 + 4K(NO3)

43.88 mL X mL

0.3842 M 0.2089 M

mol 🡪 mol 🡪 L

0.04388 L 0.3842 mol Cu(NO3)2 4 mol KI 1 L = 0.1614 L KI

 1 L 2 Cu(NO3)2 0.2089 mol

**4.4: Reaction yields**

**20.** The following quantities are placed in a container: 1.5 E24 atoms of hydrogen, 1.0 mol of sulfur, and 88.0 g of diatomic oxygen.

(a) What is the total mass in grams for the collection of all three elements?

(b) What is the total number of moles of atoms for the three elements?

(c) If the mixture of the three elements formed a compound with molecules that contain two hydrogen atoms, one sulfur atom, and four oxygen atoms, which substance is consumed first?

(d) How many atoms of each remaining element would remain unreacted in the change described in (c)?

(a) 1.5 E24 atoms H 1 mol 2.02 g = 5.0 g Sum = 5.0 + 32 + 88.0 = 1.2 E2 g

 6.02 E23 1 mol
1.0 mol S 32.06 g = 32 g

 1 mol

 (b) 88.0 g 1 mol O2 2 atoms O = 5.5 mol O2 Sum = 2.5 + 1.0 + 5.5 = 9.0 mol

31.98 g 1 molecule

(c) H + S + O2 🡪 SH2O4 S is limiting
 2.5 1.0 2.75 (5.5) mol

(d) 1.0 mol S 2 mol H = 2.0 mol H needed; 2.5 mol – 2.0 mol = 0.5 mol H left

 1 mol S

 0.5 mol H 6.02 E23 atoms = **3.01 E23** **atoms H** are left

 1 mol H

 1.0 mol S 2 mol O2 = 2.0 mol O needed; 2.75 mol – 2.0 mol = 0.75 mol O2 left

 1 mol S

 0.75 mol O2 6.02 E23 molecules 2 atoms O = **9.0 E23 atoms O** are left

 1 mol O2 1 molecule O2

**21.** What is the limiting reactant in a reaction that produces sodium chloride from 8 g of sodium and 8 g of diatomic chlorine?
2Na + Cl2 🡪 2NaCl

 8 g 8 g

 8 g 1 mol Na 2 mol NaCl = 0.348 mol NaCl

 22.99 g 2 mol Na

 8 g 1 mol Cl2 2 mol NaCl = 0.226 mol NaCl 🡪 Cl2 is limiting

 70.90 g 1 mol Cl2

**22.** A sample of 0.53 g of carbon dioxide was obtained by heating 1.31 g of calcium carbonate. What is the percent yield for this reaction?

Ca(CO3)(s) ⟶ CaO(s) + CO2(s)
1.31 g 0.53 g

 g 🡪 mol 🡪 mol 🡪 g theoretical % yield = (actual g/theoretical g)(100)

1.31 g 1 mol Ca(CO3) 1 mol CO2 43.99 g = 0.576 g CO2 theoretical yield

 100.06 g 1 mol Ca(CO3) 1 mol CO2

% yield = (0.53 g/ 0.576 g)(100) = 92.0%

**23.** Citric acid, C6H8O7, a component of jams, jellies, and fruity soft drinks, is prepared industrially via fermentation of sucrose by the mold Aspergillus niger. The equation representing this reaction is:

C12H22O11 + H2O + 3O2 ⟶ 2C6H8O7 + 4H2O

What mass of citric acid is produced from exactly 1 metric ton (1.000 E3 kg) of sucrose if the yield is 92.30%?

C12H22O11 + H2O + 3O2 ⟶ 2C6H8O7 + 4H2O

 1.ooo E6 g 🡪 mol 🡪 mol 🡪 g\*0.923

1.000 E6 g 1 mol sucrose 2 mol citric acid 192.07 g = (1.122 E6 g)(0.923) 342.23 g 1 mol sucrose 1 mol citric acid = 1.036 E6 g

**24.** How many molecules of the sweetener saccharin (C7H5NO3S) can be prepared from 30 C atoms, 25 H atoms, 12 O atoms, 8 S atoms, and 14 N atoms?



25 atoms H 1 molecule = 5 molecules

 5 atoms H

 12 atoms O 1 molecule = 4 molecules 🡪 O limiting a yield of 4 molecules

 3 atoms O

8 atoms S 1 molecule = 8 molecules

 1 atom S

14 atoms N 1 molecule = 14 molecules

 1 atom N

**25.** The phosphorus pentoxide used to produce phosphoric acid for cola soft drinks is prepared by burning phosphorus in oxygen.

(a) What is the limiting reactant when 0.200 mol of P4 and 0.200 mol of O2 react according to: P4 + 5O2 ⟶ P4O10

(b) Calculate the percent yield if 10.0 g of P4O10 is isolated from the reaction.

(a) Given equal moles of reactants but need 5X as much O2, so O2 is limiting.

(b) 0.200 mol O2 1 mol P4O10 283.78 g = 11.4 g theoretical yield

 5 mol O2 1 mol P4O10

 % yield = (10.0 g / 11.4)(100) = 87.7%

**4.5: Quantitative chemical analysis**

**26.** In a common medical laboratory determination of the concentration of free chloride ion in blood serum, a serum sample is titrated with a Hg(NO3)2 solution.

2Cl−1(aq) + Hg(NO3)2(aq) ⟶ 2NO3−1(aq) + HgCl2(s)

What is the Cl−1 concentration in a 0.25-mL sample of normal serum that requires 1.46 mL of 8.25 × 10−4 M Hg(NO3)2(aq) to reach the end point?

2Cl−1(aq) + Hg(NO3)2(aq) ⟶ 2NO3−1(aq) + HgCl2(s)

0.25 mL 1.46 mL

X M 8.25 E-4 M

0.00146 L 8.25 E-4 mol 2 mol Cl-1 = 9.64 E-3 M Cl-1

 1 L 1 mol Hg(NO3)2 0.000250 L

**27.** The principal component of mothballs is naphthalene, a compound with a molecular mass of about 130 amu, containing only carbon and hydrogen. A 3.000-mg sample of naphthalene burns to give 10.3 mg of CO2. Determine its empirical and molecular formulas.

CxHy + O2 🡪 CO2 + H2O

 3.ooo E-3 g 0.0103 g

 MW 130 g/mol

3.000 E-3 g 1 mol anpthalene = 2.31 E-5 mol napthalene

 130 g

 0.0103 g 1 mol CO2 = 2.34 E-4 mol CO2

 43.99 g

2.34 E-4/2.31 E-5 = 10 C in naphthalene 🡪 130 – (10)(12.01) = 9.9 g/mol H = 9 H

C10H9 though should be C10H8

**28.** What volume of 0.08892 M H(NO3) is required to react completely with 0.2352 g of potassium hydrogen phosphate?

2H(NO3)(aq) + K2(HPO4)(aq) ⟶ H3(PO4)(aq) + 2K(NO3)(aq)

 0.08892 M 0.2352 g

 L? 🡨 mol 🡨 mol

 0.2352 g 1 mol 2 mol H(NO3) 1 L = 0.03035 L

 174.14g 1 mol K2(HPO4) 0.08892 mol

**29.** What volume of a 0.3300-M solution of sodium hydroxide would be required to titrate 15.00 mL of 0.1500 M oxalic acid?

(C2O4)H2(aq) + 2Na(OH)(aq) ⟶ Na2(C2O4)(aq) + 2H2O(l)

15.00 mL X mL

0.1500 M 0.3300 M

0.01500 L 0.1500 mol 2 mol Na(OH) 1 L = 0.01364 L

 1 L 1 mol (C2O4)H2 0.3300 mol

**30.** Potassium acid phthalate, K(HC6H4O4), or KHP, is used in many laboratories, including general chemistry laboratories, to standardize solutions of base. KHP is one of only a few stable solid acids that can be dried by warming and weighed. A 0.3420-g sample of K(HC6H4O4) reacts with 35.73 mL of a Na(OH) solution in a titration.

What is the molar concentration of the Na(OH)?

 K(HC6H4O4)(aq) + Na(OH)(aq) ⟶ KNa(C6H4O4)(aq) + H2O(aq)
 0.3420 g 35.73 mL

 X M

 0.3420 g 1 mol K(HC6H4O4) 1 mol Na(OH) = 0.05313 M

 180.17 g 1 mol K(HC6H4O4) 0.03573 L